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POTENTIAL VULNERABILITY ISSUES FOR DRUM-TYPE PACKAGES

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ABSTRACT

Type B and Type A fissile drum packages are required to undergo a series of tests that simulate both normal conditions of transport (NCT) and hypothetical accident conditions (HAC) as specified in 10 CFR Part 71. In particular for HAC, it must be demonstrated that the package can withstand a 30 ft. drop in the most unfavorable orientation without damage that would compromise its ability to survive a subsequent regulatory fire test. Historically, it has usually been assumed that the most unfavorable orientations are those that allow the maximum amount of available kinetic energy to be used for package deformation. Therefore, drop test orientations have been mostly limited to Top-Down, Bottom-Down, Side, and C.G. Over Top-Corner. (Where C.G. refers to the center of gravity of the package.) Here, it is shown that shallow angle top impact, where a portion of the translational kinetic energy of the package is transformed into rotational kinetic energy at impact, may also be a likely orientation that will lead to failure of drum packages that use bolted ring closures.

INTRODUCTION

Drum packages approved under 10 CFR Part 71 include both Type AF and Type B packages. Type A fissile (AF) packages are generally intended for the transport of low-enriched or other Type A quantities of uranium in the form of powder, pellets, fuel elements, or scrap. Type B packages are generally intended for the transport of high-enriched uranium, plutonium, or radiographic devices and source changers containing special form gamma-emitting sources. The packages are designated as Type B(U), B(M), or B( ), with the F (fissile material) designator as appropriate. A typical design of these drum packages is illustrated in Figure 1.

As seen in Figure 1, the package consists of a removable-head drum as the outer packaging, with insulating (and energy-absorbing/stiffening) material between the drum and the inner container enclosing the radioactive material. The insulation may be fiberboard, plywood, hardwood, foam, fiberglass, vermiculite, concrete, or other similar material.

For Type AF packages, the inner container may be another drum or similar packaging designed primarily to maintain geometry control of the fissile material. For Type B packages, the inner container is typically either a leak-testable containment vessel, which provides both geometry control and containment, or radiographic packaging containing a special-form gamma source. For certain forms of plutonium, two containment vessels may be required by 10 CFR 71.63(b).

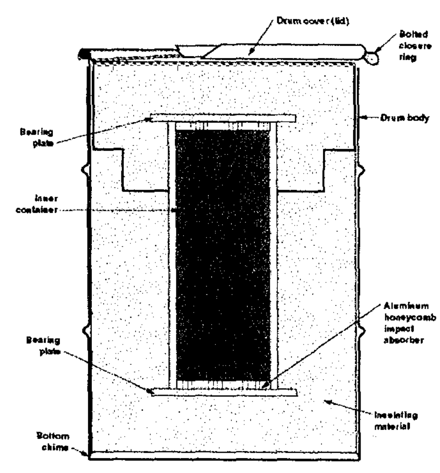

Figure 1 Representative drum package certified under 10 CFR Part 71

In addition to the drum and insulating material, a few other components are sometimes included in drum packages.

Some drum packages are intended to transport radioactive material with substantial gamma emission. In most cases these are packages for radiographic devices, which contain their own internal shielding. In a few cases, however, drum packages have been designed to transport other material (e.g., plutonium) for which additional shielding is necessary. These packages may have a cylindrical lead shield that surrounds the containment system. If the contents have a small diameter or are heavy, bearing plates have sometimes been installed above and below the containment system and shielding in order to distribute the load more evenly to the insulating (energy-absorbing) material.

It is the structural performance during regulatory testing of heavy drum packages with double containment and shielding, and the combined effort of designers and certifying officials that is necessary to ensure that all plausible package failure modes are indeed tested, that is addressed here.

STRUCTURAL CHARACTERISTICS AND CAPABILITIES OF DRUM PACKAGES

In addition to tests of specific drum packages to demonstrate compliance with 10 CFR Part 71, a number of general tests and evaluations have been performed over the years in order to understand the structural capabilities of drum packages. In some cases these tests have resulted from a desire to compare different types of drums and drum components or to assess the impact of new regulatory requirements, while in others they were performed to understand drum performance observed in actual or staged transportation accidents.

Savannah River Plant Drum Package Tests

During 1969 and 1970 the Savannah River Plant developed a number of drum packages, none of which appear to be currently in use for transportation. As part of this development, 20 package configurations were tested to assess the structural performance of various drums and insulating materials, and eight tests were conducted to assess the thermal performance of insulating materials. At the request of the Atomic Energy Commission (AEC), the results of these tests were documented [Lewallen, 1972] for use at other facilities and for possible guidance in formulating new specifications by AEC and DOT. General conclusions of these tests include:

- Each configuration of a drum package has different structural and thermal capabilities.
- Outer drums must have adequately strong closures, which are primarily dependent on the size of the curl, the type of locking lugs, and thickness of metal. Military Standard drums were chosen for all packages because of their strength and close tolerances. Curls of military drums were 1.14 cm (0.45 in.), larger than those of typical DOT Specification drums. Closure rings must be at least 12 gauge and have dropped-forged lugs, with bolts of high-strength steel. Although the report recommended 3/8-in. bolts torqued to 20 ft.-lb., current drum packages approved under 10 CFR Part 71 generally have 5/8-in. bolts tightened to approximately 50 ft.-lb.
- Gaskets in the drum covers reduced the tight metal-to-metal contact and tended to act as a spring that contributed to loss of the cover upon impact. Consequently, the use of gaskets was not recommended.
- Closure rings should be tapped with a soft hammer during torquing in order to relieve friction forces around the periphery of the closure as the bolt is tightened.
- Insulating material must fit tightly within the drum and around the inner container. A maximum gap of 0.635 cm (0.25 in.) was recommended.
- Industrial Celotex insulating material offered the best combination of resilience, thermal insulation, material and fabrication cost, life expectancy, and lack of personnel hazard. (Celotex is a brand name of fiberboard made from sugar cane fibers bonded together with an organic glue.) This conclusion was limited, however, to packages in which the decay heat was sufficiently low so that temperatures in the fiberboard did not exceed 121°C (250°F).
- Venting of the drum is necessary to relieve pressure from gases released from heated insulating material. Vents should be located around the circumference of the drum body, near the curl. (Vents on drum heads were sometimes blocked, depending on the orientation of the package.) Vents should be covered with plastic plugs, waterproof tape, or other suitable material that will exclude moisture under normal conditions of transport.
- For fiberboard insulating material (or other insulating material not intended for high temperatures), a ring of noncombustible porous refractory material should be

placed under the vents. A blanket of felted refractory insulation should also be placed under the drum cover to provide a tight fit and to add thermal protection.

The performance of drum packages depends significantly on specific details of the drum, insulating material, other drum components, and the contents. A few studies [NUREG/CR-0558, 1979 and NUREG/CR-0992, 1979] have attempted to establish minimum design specifications which would assure that drum packages satisfy the requirements of 10 CFR Part 71 (e.g., the maximum package weight for a given size drum). Examining the various tests and analytical modeling on drum packages in these studies, and others, provide qualitative insight on the capabilities of drum packages and on potential failure mechanisms during the 10 CFR Part 71 tests.

Highway Accident Evaluations Involving Drums Filled with Natural Uranium Concentrate

In the late 1970s, two accidents [NUREG/CR-0558, 1979 and NUREG/CR-0992, 1979] occurred involving the transport of natural uranium concentrate (yellowcake) in 208-liter (55-gallon) drums*. Because these drums had no insulating material to absorb energy and enhance their structural performance in the accidents, the quantitative evaluations of drum performance conducted after the accidents are not as relevant to this report as the qualitative analysis of the mechanism of drum failure.*

Prior to both accidents, the drums were being transported inside a closed trailer, with approximately 25 drums positioned over the rear axle and a similar number located at the front of the trailer. The trailers had limited bracing to maintain drum position. In one accident the predominant trailer motion appeared to be sudden deceleration, which caused the drums at the rear of the trailer to slide forward and collide with those in the front. In the other accident, the initial truck speed was low, and the predominant motion appeared to be overturning of the trailer, which caused the drums on the left side to slide into those on the right. Because of small variations in drum sizes and rolling hoop locations, the tops of drums were both higher and lower than adjacent drums during the crushing. In both accidents the trailers eventually overturned, and a number of packages were ejected through tears in the trailer.

The drums in the first accident were 18-gauge Rule 40 drums with closure rings secured by 5/16-in. bolts. Drums in the second accident were reconditioned 16-gauge DOT 17H drums with apparently stronger closure rings secured by 5/8-in. bolts.

General conclusions reached during the reconstruction of the accident scenario include:

- Deformation in the drums was primarily in the radial direction. This deformation appeared to result from quasi-static crushing inside the trailer. (In quasi-static crushing the application time of the crushing force is much longer than the fundamental response time of the drum array.)
- Except for three drums with small tears in a seam (seam location was not specified), all drums failures were due to separation or total loss of the cover.
- Separation of the cover was attributed to two distinct mechanisms consistent with observed drum damage and follow-on laboratory tests. If a crushed drum was higher than adjacent drums (drum "up" position), the cover deformed only slightly. The closure ring deformed locally, but retained its circular shape as the cover pulled out. On the other hand, if a crushed drum was lower than adjacent drums (drum "down" position), the cover and drum elongated as the body was crushed. As the closure ring and drum deformed into an elliptical shape, the edges of the cover slipped from under the ring at the ends of the major axis of the ellipse. The cover then buckled in a single crease along this axis, leaving a large opening at one or both sides of the top of the drum.

Currently Approved Drum Packages

Closure systems on most current drum packages approved under 10 CFR Part 71 have the stronger 12 gauge closure rings with drop forged lugs secured by 5/8 inch bolts torqued to 50 ft-lbs. It has been generally thought that the most plausible failure mode of these packages during a 30 ft. drop test is the drum lid being knocked off by the impingement of the contents and shielding against the lid during impact with the ground. Or, possibly the splitting of the drum body seam in a side impact. This is why, traditionally, orientations in drop testing have mostly been limited to C.G. over Top-Corner, Nearly Top-Down, and Side Drop. The first two orientations allow the greatest amount of contents and shield translational kinetic energy to be used for deformation of the closure area. Figure 2 shows the damage from dropping a Type B drum package with lead shielding 30 ft. onto an "unyielding"

* Natural uranium LSA transport is regulated by the DOT under 49 CFR

surface in the C.G. over Top-Corner orientation. It can be seen that while there is gross plastic deformation in the closure region, there is no evidence of lid separation. If a package designer believes that the most unfavorable orientation has been tested, it is tempting to conclude that the package has "passed" the drop test requirement. However, the studies of the drums involved in vehicle accidents indicate lid buckling is also a possible failure mode.

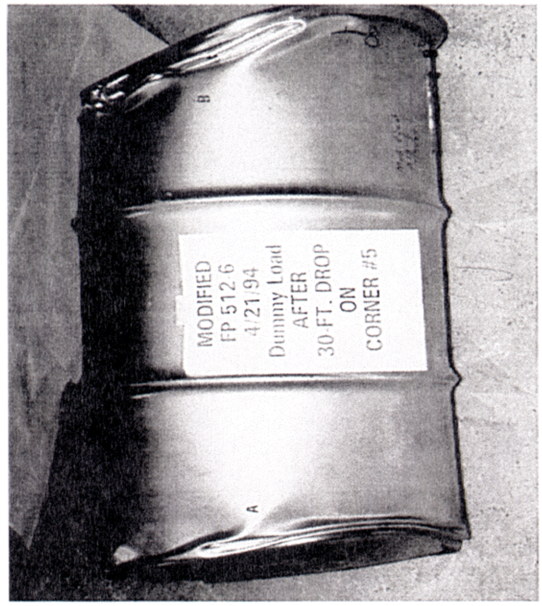

Figure 2 Closure Area Damage From a C.G. –Over-Corner Drop Test

Upon impact in shallow angle drops (measured from the horizontal), part of the contents and lead shield's translational kinetic energy will be transferred into rotational kinetic energy with the balance available for closure area deformation. The shallower the angle, the more energy going into rotation. But, the shallower the drop angle, the greater the magnitude of the impact load in the plane of the lid. The lid in-plane force will increase with decreasing drop angle until slipping occurs at the point of contact and then drop off (the angle at which slipping occurs will depend on the coefficient of static friction between the contact regions). If, before slipping occurs, the in-plane load is large enough, the lid will buckle and expose the package contents as indicated in the vehicle accident studies mentioned above. Figure 3 shows a lid buckling failure from a 30 ft shallow angle drop of the same package design and weight as in Figure 2. This failure was surprising, in as much as this package design had survived other 30 ft drop tests in, what was thought, the most unfavorable orientations. "Catching" this failure mode was the result of an iterative effort between the package designers and the reviewers for package certification.

Figure 3 Lid Buckling Resulting From a Shallow Angle Drop Test

These results tend to indicate that the heavier packages, i.e. packages containing lead shielding, may be more vulnerable to failure via lid buckling than failure by direct contents/lid impact. Therefore, these package designs most likely will require some type of structural modifications to "stiffen" the closure area in order to comply with 10 CFR Part 71.

ENHANCED DRUM DESIGNS

The most common method of closure for drum packages is by a bolted closure ring with drop-forged lugs. Concern over failure of this closure system, particularly as the result of lid buckling, has resulted in a number of proposed alternatives to the conventional closure ring design. In some cases, these alternatives have been implemented in DOE packages. Several of these alternatives are discussed below.

Drum Cover with Skirt Extension

This alternative design was proposed and tested in the mid-1970s as part of program by the U.S. Energy Research and Development Administration (ERDA) to improve the closure systems of conventional drum packages [Otts, 1976]. (This concept was also proposed during the accident evaluation of drums that transport uranium concentrate, as discussed previously.) A skirt welded to the drum cover increases the load necessary to induce buckling in the lid. If buckling does occur, the skirt acts to prevent the formation of gaps between the drum and lid that may expose the insulation. Tests conducted under the ERDA program demonstrated that a 152-mm (6-in.) skirt more than doubled the minimum package weight necessary to produce lid separation and expose the fiberboard after the regulatory free-drop. Note that this alternative requires a modification to a standard drum cover, but not the drum body. This concept is illustrated in Figure 4.

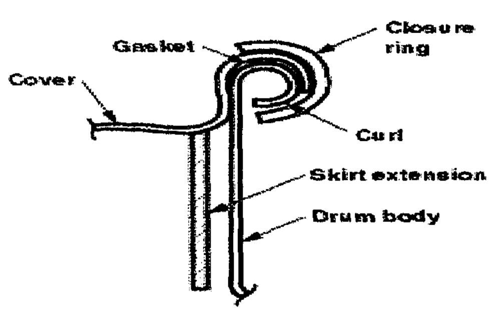

Figure 4 Skirt extension

Inner Cover

Similar to the skirt-extension concept, another alternative proposed in the ERDA program was the use of an inner cover. This inner cover was a "cup-like" lid that fit over the insulating material under a normal drum lid. A minimum of 75 mm (3 in.) of fiberboard was recommended between the outer cover and inner lid and between the inner lid and the inner container. Tests conducted using an inner cover with 152-mm (6-in.) sides under the drum lid resulted in exposure of the fiberboard insulating material at approximately 1.6 times the package weight needed without an inner lid. This alternative adds another drum component but does not require modification of the conventional drum cover, body, or closure ring.

C-Clamps

A third alternative proposed in the ERDA program was the use of standard C-clamps to tighten the drum cover to the curl. Suggested configurations included six C-clamps in conjunction with a normal closure ring or 12 C-clamps without a closure ring. Performance of these configurations was essentially the same as that of the inner lid. This alternative necessitates no modifications to conventional drum designs.

Closure-Ring Modifications

A number of alternative designs to closure rings have been proposed, each involving some type of extension of the ring along the side of the drum. Tests conducted under the ERDA program indicated that the benefits of these designs appeared marginal and increased the difficulty in attaching the closure ring.

Cover Brackets

As illustrated in Figure 5, this concept uses a J-bracket arrangement. One end of the bracket is bolted to an extension welded onto the drum cover, and the other end grips the drum cover and curl. This closure method is currently used in the DOE UC-609 package. It requires a modification to a standard drum cover, but not the drum body, and eliminates the need for a closure ring.

Bolted Cover

This concept, illustrated in Figure 6, consists of a blind-flange arrangement in which the drum cover is bolted directly to the body. This closure system significantly increases the load necessary to buckle the cover and reduces the size of gaps that could form between the drum cover and the body. This concept necessitates modification of both the conventional drum cover and body.

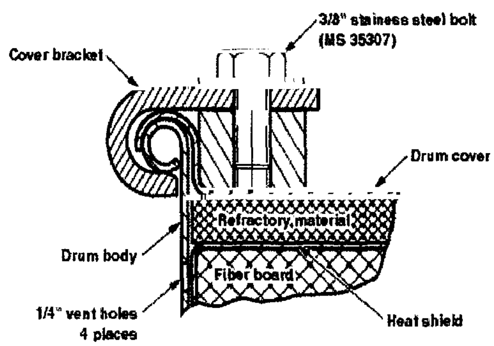

Figure 5 J-bracket closure

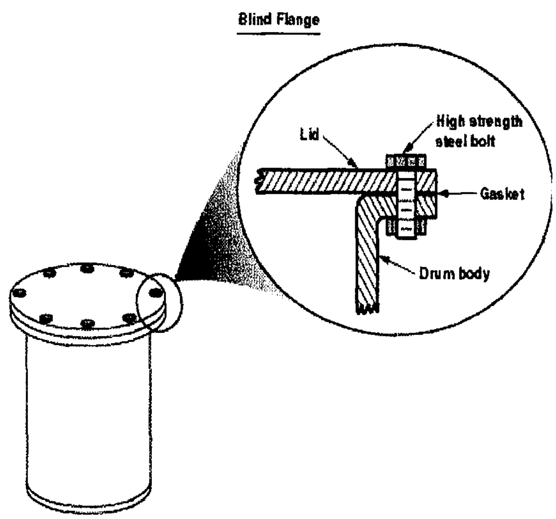

Figure 6 Bolted cover

Cover Stiffeners

Some drum packages have corrugations in their covers to increase the stiffness. Corrugated covers are commercially available for conventional drum sizes. The stiffness of covers could also be enhanced by welding cross-members as shown in Figure 7. Although this concept would clearly result in a cover that is more resistant to buckling, no testing of this method was identified in the literature. This alternative necessitates a modification to a standard drum cover, but not the drum body.

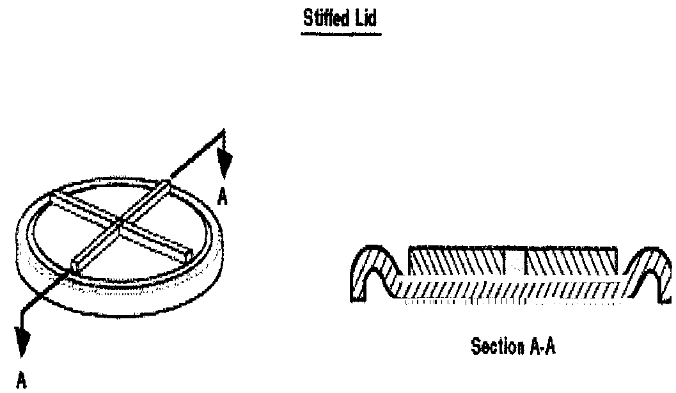

Figure 7 Cover stiffeners

Protective Cage

This alternative, once used in a DOE package, incorporates a high-strength steel cage to prevent or reduce the direct load to the drum closure system during an impact. The cage deflects the impact load away from the closure area and absorbs impact energy through plastic deformation. Figure 8 illustrates this concept. Although this alternative requires an additional drum component, it does not require modification to the conventional drum body or cover.

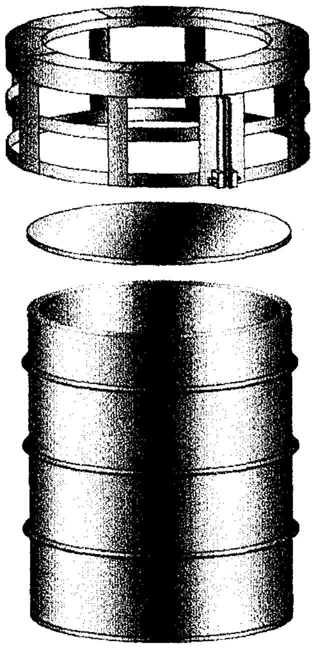

Figure 8 Protective cage

CONCLUSIONS

It has been predicted by qualitative analysis and seen in actual testing that any package design may have more than one failure mode. Also, qualitatively similar drum packages may not exhibit the same failure modes or have the same vulnerability to a particular failure mode depending on the specifics of the contents and overpack. However, compliance with 10 CFR Part 71 demands that the required drop testing explore all plausible failure modes of a package design. Determining all the plausible failure modes of a particular design and ensuring they've been adequately addressed in testing should be and is an iterative process between package designers and certifying officials.

As an example of this process, it has been demonstrated that drum packages using a bolted ring closure can be vulnerable to failure by lid buckling during a low angle impact, even though drop tests of the same package design in other orientations did not produce failures. This failure has resulted in a package closure re-design incorporating one of the previously mentioned structural enhancements.

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